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VERTICAL WALL SOLAR AIR HEATERS

A Design and Construction Manual

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

VERTICAL WALL SOLAR AIR HEATERS
A Design and Construction Manual

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August 1982

Prepared for

Montana Department of Natural Resources and Conservation
1520 East 6th Avenue, Helena, Montana 59620
Renewable Energy and Conservation Program
Grant Agreement Number RAE-82-1019

Available from

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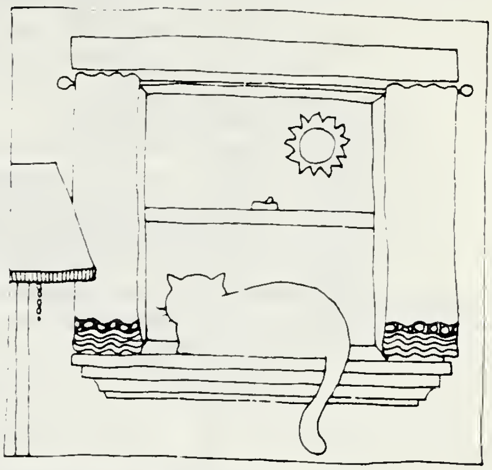
VERTICAL WALL SOLAR COLLECTORS

Solar collectors are space heating devices which use the sun's energy as a source of fuel. Solar collectors come in a wide variety of styles, sizes, shapes, designs, and prices. They can be used to heat air for space heating, water for household use, pools or spas, and some systems heat both air and water. Many new homes are being designed to capture and store the sun's energy "passively" (without actually using solar collectors).

This book is about vertical wall solar air collectors. These "retrofit" collectors are a relatively low technology device which can work well in Montana's climate if properly designed and constructed. Many people prefer them to roof-mounted collectors since vertical wall collectors tend to blend into the building better than most roof-mount collectors.

Vertical wall collectors are ideal for do-it-yourselfers since they are relatively easy to design, build, and install and are made from locally available materials.



1. Cat Absorbing Solar Heat

VERTICAL COLLECTORS

Advantages

1. Relatively easy to build
2. Can be mounted flat on wall
3. Short duct runs
4. Captures reflected light from snow
5. Can be protected from summer sun by use of an overhang or cover
6. No tendency towards snow and ice buildup
7. Easier to get at to clean glazing
8. Less heat loss from snow and wind

Disadvantages

1. Approximately 6% loss of solar penetration per square solar penetration per square foot' compared to collectors on a 60° tilt. (However, adding reflectors can greatly increase solar penetration.)
2. More subject to vandalism
3. Misses most of the diffuse radiation from overcast skies

Can I Build My Own?

YES . . . definitely! Thousands of people have built and installed their own solar collectors with great success. Solar collectors can effectively lower heating costs and it is very rewarding to have built them yourself. And the cost of solar heat systems is reduced dramatically when you provide the labor yourself . . . which also shortens the payback period.

BEFORE attempting to build solar collectors, however, it is imperative that you understand the principles of solar collector design, construction, and installation, that you know which materials are appropriate, and that you are willing to take the time to build them correctly. Time and money are invested needlessly if your collectors work inefficiently.

Vertical wall solar air collectors are not technically difficult to design and build.

What Should I Consider Before Building?

WEATHERIZATION COMES FIRST

Before you spend money on solar collectors, your home should be insulated and weatherized. This means adequate insulation in the attic, walls, and crawl spaces, doors and windows that are caulked and weatherstripped, and storm windows in place. Insulation is more cost-effective than solar collectors and the heat gained from the collectors will remain longer in the house that is well insulated.

SITE FEASIBILITY

Is your site situated for maximum solar gain during winter months? A collector should face as close to true south as possible. Variations of 15 to 25 degrees east or west will not reduce collector performance drastically.

Does your building's south wall have adequate room to mount collectors? Otherwise you will have to mount them on the roof.

Are there any buildings, trees, hills, or large objects which would shade the collectors in the winter? If so, are you able and willing to remove them?

FINANCIAL FEASIBILITY

A solar collector's **purpose** is to save you energy and, thus, money. Some financial considerations to take into account include . . .

. . . Although systems should be made from reasonably high quality, durable materials, they don't have to be expensive to be effective. Quality, not cost, determines efficiencies.

. . . Solar space heating is most effective where it is sunny and very cold. Sunny, cold climates mean high fuel bills and faster payback.

. . . Rising fuel prices and future inflation rates will affect the payback period of your system. The more expensive conventional fuels become, the more cost-effective solar heating systems become.

. . . Be aware that there are federal and state tax credits which apply to solar heating systems. More information on these credits appears at the end of this book.

BUILDING MODIFICATIONS

Are you willing to make changes in your home's appearance? Are you willing to cut holes in the wall to duct the hot air into the house from the collector? Vertical collectors are occasionally mounted into the wall, requiring removal of siding (although this is not absolutely necessary), duct runs and wiring are necessary for active systems, grilles must be mounted in walls for cold air inlets and hot air outlets. These modifications are relatively minor but they should be considered before building begins.

OTHER IMPORTANT CONSIDERATIONS

Materials for solar collectors will not become cheaper as time passes. A system installed today starts generating immediate savings.

New technology is not apt to come up with a "magic solution" to the energy shortage. A solar heat system installed today will not become obsolete overnight.

How Do Collectors Work?

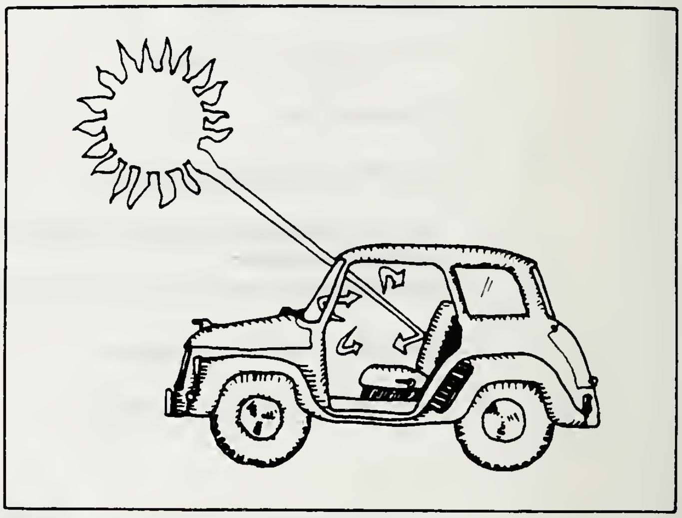
A solar collector is a particular combination of parts that are sized to work as well as possible together. It is an integrated whole. It is a system.[2]

A solar collector works on the simple principle known as

THE GREENHOUSE EFFECT

For example, the greenhouse effect occurs when you leave your car parked in the sun with the windows closed. The car's window glass admits the sun's rays (shortwave radiation) into the car, where they strike the interior surfaces. These surfaces absorb the radiation, become warm, and re-radiate their heat in the form of longwave radiation to the surrounding air. Because glass does not easily transmit longwave radiation, a large amount of heat is trapped inside the car.

In a solar collector, the sun's rays pass through a transparent glazing, strike the absorber, and are converted from sunlight into heat. The heat cannot easily escape because the glazing traps it within the collector box. The heat is absorbed by the air and is delivered to the residence either through natural convection (passive system) or with blowers and controls (active system).



2. The Greenhouse Effect

3. Typical Air Collector Cross-Section

For More Information
(on solar heating in general and home weatherization)

THE SOLAR DECISION BOOK by Richard Montgomery with Jim Budnick. Dow Corning Corp., Midland, MI 48604
HOMEOWNER'S SOLAR SIZING WORKBOOK by Paul Bendt for the Solar Energy Research Institute, 1617 Cole Blvd., Golden, CO 80401
HOME RETROFITTING (article), Solar Age Magazine (July 1979), Church Hill, Harrisville, NH 03450
THE NATIONAL SOLAR HEATING AND COOLING INFORMATION CENTER, P.O. Box 1607, Rockville, MD 20850. Call 1-800-523-2929
THE MONTANA ENERGY-SAVING HANDBOOK FOR HOMEOWNERS, A DNRC publication (included in this packet of information)
SOLAR ENERGY RESEARCH INSTITUTE, 1617 Cole Blvd., Golden, CO 80401
ALTERNATIVE ENERGY RESOURCE ORGANIZATION, 424 Stapleton Blvd., Billings, MT 59101

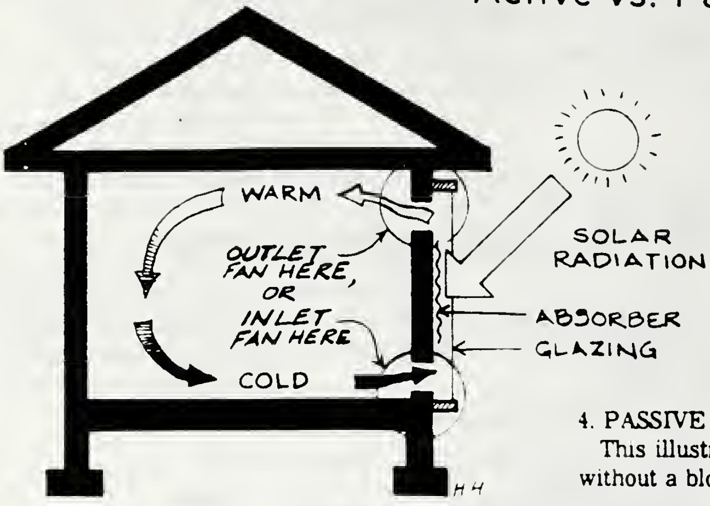
MAJOR COMPONENTS OF FLAT-PLATE SOLAR COLLECTORS*

COMPONENT	USE/FUNCTION	IMPORTANT CONSIDERATIONS	COMMONLY USED MATERIALS
Glazing	-reduces energy losses from the collector -protects collector from environment	-transmissivity -durability -maximum operating temperature -cost	-glass -plastics -thin films
Absorbers	-absorbs solar energy which strikes it and converts it to heat	-ability to conduct heat -should have corrugated or textured surface	-steel -copper -aluminum -selective surfaces
Coatings	-increases energy absorption and protects absorber -selective coatings used to reduce radiation losses	-compatibility with absorber material -absorptance -emittance -effects of high temperature -durability -cost	-flat black acrylic -barbecue and stove paint -selective paints
Insulation	-reduces heat loss from collector to outside environment -prevents charring of wood interiors	-proper R-Value -compatibility with -maximum operating temperature of collector	-fiberglass -glass foam -foamed thermoplastic
Sealant	-binds materials together -prevents air leakage -allows for differences in thermal expansion of system materials	-adhesion -elasticity -durability in temperature extremes and thermal cycling, weather & solar exposure -outgassing	-butyl rubber calk -urethane caulk -silicone caulk
Frame	-houses all components -provides support for installation of collector on structure -protects components from environment	-durability under given environmental conditions	-aluminum -steel -plastics -wood

*adapted from Montana Renewable Energy Handbook, a Montana Department of Natural Resources Publication.

SOLAR SYSTEM DESIGN

Active vs. Passive Systems



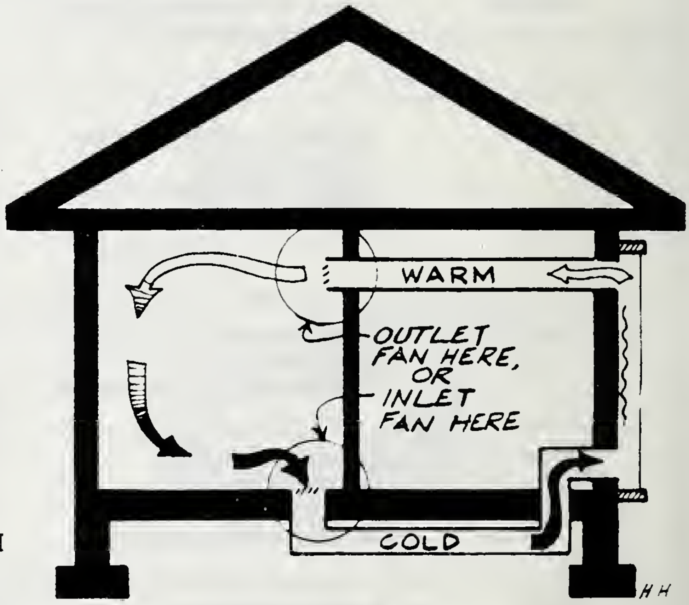
PASSIVE SYSTEMS work by natural convection. As air is heated in the collector it rises to the top and passes into the room. At the same time, cool air is drawn from the house through an inlet at the bottom of the collector, which in turn is heated. Passive systems work best when located next to the rooms they are to heat and when the space is not extremely large. Passive systems have the advantage of working when the electricity goes off.

4. PASSIVE SYSTEM
This illustration shows a collector which could be used with or without a blower.

ACTIVE SYSTEMS use a blower to increase the air flow and collector efficiency. A blower is used to move heated air through the ductwork. Active systems can be wired to work automatically or manually.

Active systems generally run at cooler temperatures which results in a more efficient collector (less heat loss). Warmed air can be brought greater distances and rooms can be heated more equally.

More expense is usually incurred in active systems since it is necessary to purchase blowers and controls. Electricity is required for the blowers and controls which will also increase the cost of the system, although the amount of electricity used is relatively minimal.



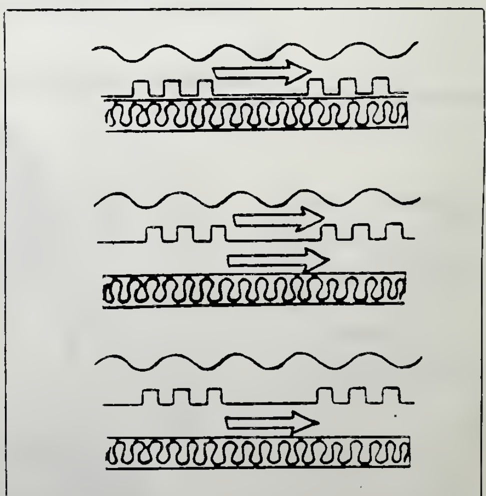
5. ACTIVE SYSTEM

BACKPASS vs. FRONTPASS

There are three ways to move the air through the collector box:

1. In front of the absorber
2. Behind the absorber
3. In front of and behind the absorber

Running the air behind the absorber has been found to be the most efficient method for space heating purposes since this creates a dead air space between the absorber and glazing and thus reduces heat loss through the glazing.



6. Illustration of Frontpass, backpass and combination.

BACKPASS MOST EFFECTIVE

EXCEPTION: There is one situation in which it is more cost-effective to move the air in front of the absorber. That is on metal-wall buildings. In this design the metal wall of the building is painted with the absorber coating, using the metal wall itself as the absorber plate. The wall is framed and glazed and the air is passed in front of the wall/absorber. In this situation it would be too complicated and expensive to design the system with the air running behind the metal wall.

ORIENTATION

A solar collector should face true south. Variations of 10 to 25 degrees from south are acceptable and will not reduce collector efficiency dramatically. However, to be cost-effective, a collector should not face more than 25 degrees off of true south.

COLLECTOR SIZING

What size collector will you need to heat your living space during the winter? Be aware that it is not economical to build a system which provides 100% of your home's heat in the coldest days of winter.

A collector which provides 30% - 40% of your heat in January can provide 75% of the heat in October and April and probably will yield about 50% - 60% of your year-round heating needs.

First, decide which rooms you regularly use in the daytime. Heating bedrooms, or rooms not normally used in daytime, is not cost-effective.

In Montana's climate a daytime system should have approximately one square foot of collector for every eight to ten square feet of floor area to be heated.

1 SQ. FT. COLLECTOR/8-10 SQ. FT. LIVING AREA

FOR EXAMPLE:

Living Room (12x16)	= 192 sq. ft.
Kitchen (10x10)	= 100 sq. ft.
Family Room (12x14)	= 168 sq. ft.
Bathroom (5x10)	= 50 sq. ft.
	510 sq. ft. floor area

$$\frac{\text{510 sq. ft. floor area}}{\text{10 sq. ft. collector}} = \text{51 sq. ft. collector}$$

Moving the Air

There are several factors which affect air movement in the system. These include (1) baffling configurations, (2) air gap, and (3) blower and duct size. When designing collectors the objective is to keep the collectors running as cool as possible, relatively speaking (between 90°F and 120°F), and yet warm enough to heat the living area.

Baffling Configurations

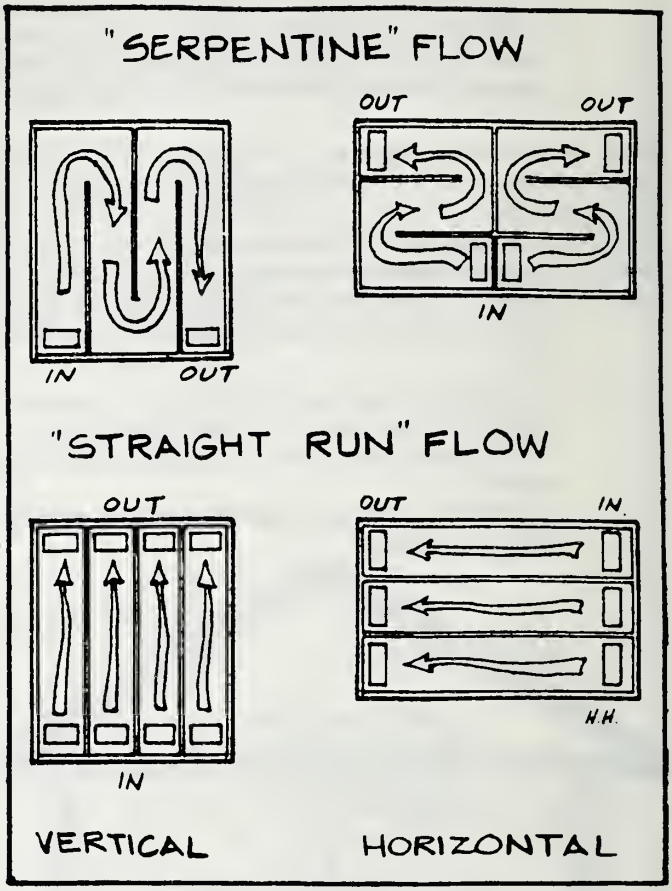
Collectors are baffled to insure that the circulating air comes in maximum contact with all portions of the absorber. There are several ways to baffle a collector, the main objectives being (1) optimum heat gain with (2) minimal heat loss and (3) maximum air flow.

Ideally, collectors should be baffled so that the air moving through them travels between 16 and 25 feet behind the absorber.[1] There are two basic baffling configurations—straight run and serpentine:

In a STRAIGHT RUN SYSTEM air flows directly from one vent to the other in a straight line. Equal amounts of air pass over all of the absorber. Straight runs eliminate sharp turns (which cause hot spots) and have lower static pressure and operating temperatures. Straight runs can reduce the static pressure problems in large systems. Baffles must run vertically in passive systems.

SERPENTINE SYSTEMS slow the air flow which gives the passing air more time to absorb heat. If the air is blown through the collector, serpentines will build up more static pressure resulting in hotter collector temperatures and increased heat loss. Pulling the air through the collector usually eliminates this problem. Serpentine configurations are useful in helping increase collector temperatures in small systems. Baffles must run horizontally on passive systems.

For proper air flow in a serpentine baffled collector, the gap between the baffle and the collector wall should be equal to the distance between the baffles (see illustration #14).



7. EXAMPLES OF BAFFLING CONFIGURATIONS

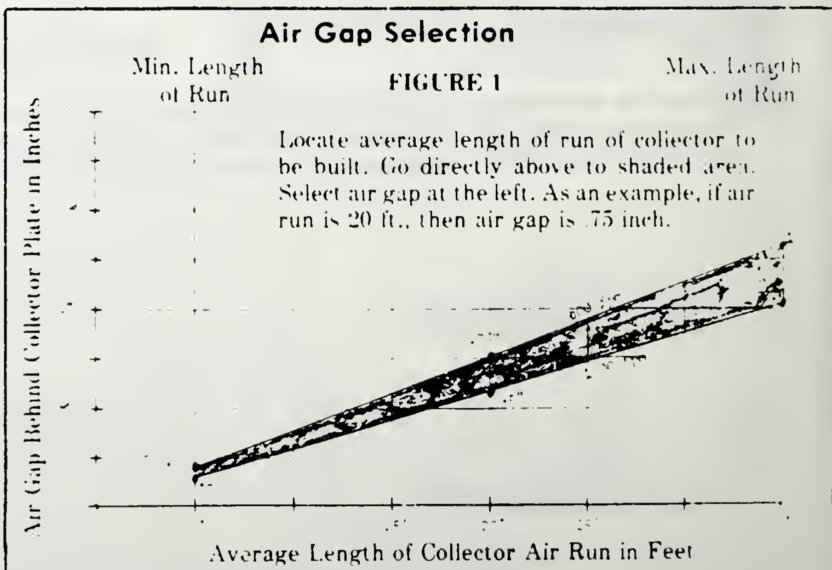
Air Gap

The air gap is the space behind the absorber through which the air flows. The air gap in the collector will range from ¼ to about 1¾ inches. This relatively narrow gap, together with corrugations or patterns on the absorber, helps create turbulence in the air which increases heat transfer to the air.

If the air gap is too small it increases the static pressure and the collectors will overheat. If the air gap is too large, air speed drops and again, the temperature rises and heat is lost from the collector.[4]

The Air Gap Chart provides a way to correctly size the air gap for a given collector. When using the chart bear in mind that (1) if the absorber has large corrugations, the air gap should be increased slightly and (2) for passive systems the air gap should be doubled.

The dead air space between the absorber and glazing should be between ¾" and 1" for the best insulating effect.



8. AIR GAP CHART

The chart above shows the air gap suggested for various lengths of run in a collector (the distance the air travels from inlet to outlet).

Blower and Duct Sizing

Duct and blower sizing are two problem areas for do-it-yourselfers who build collectors. Duct and blower size can make or break a system's performance. A proper amount of air should move through the collector for good overall efficiency.

Air encounters resistance and its flow slows down as it moves through the collector and ductwork. This resistance (static pressure) is important to blower and duct selection.

Static pressure is dependent on the (1) length, size, and configuration of the ducting and (2) the amount of velocity of air moving through this ducting.[5] A system with large ducts and straight runs will have relatively low static pressure and air will move easily through it. Small ductwork with several changes of direction will create a high static pressure situation and the blower should be carefully sized. Fittings (tees, elbows, adapters, etc.) will increase the static pressure.

SIZING THE BLOWER

A good rule of thumb for sizing the blower to the collector is to move about 3 - 4 CFM of air per square foot of collector.

AIR FLOW = COLLECTOR AREA x 3-4 CFM

For example, a 32 square foot collector (with no ducting) would need 96 to 128 CFM of air moving through it (32 X 3 = 96, 32 X 4 = 128).

The collectors discussed in this booklet will have a static pressure of approximately .2" to .3"[6] and this must be taken into account when sizing the blower.

For example, a 32 sq. ft. collector with .2" static pressure would require a 134 CFM Free Air blower to move the required 117 CFM through the collector. To use the Blower Sizing Chart below, locate the required number of CFM which should be moving through the collector under the estimated Static Pressure column to find what size of Free Air Blower you would need to purchase.

9. BLOWER SIZING CHART

	Free Air	0.1" SP	0.2" SP	0.3" SP	0.4" SP	0.5" SP	Cut Off SP
CFM	100	98	95	90	85	80	0.80"
	134	126	117	107	96	79	0.59"
	160	151	141	125	93	16	0.53"
	265	250	232	212	184	135	0.64"
	320	305	284	252	195	50	0.51"
	350	340	328	312	296	274	1.00"
	465	428	396	352	305	227	0.76"
	525	500	475	447	415	387	1.15"
	815	767	716	663	604	537	0.91"
	980	940	890	843	788	730	1.05"

S.P. refers to Static Pressure.

SIZING THE DUCT

Ductwork creates static pressure which must be taken into consideration when choosing blower size. If the static pressure of the collector and ducting combined exceed the Cut-Off Static Pressure (see Blower Sizing Chart) the fan will overload and shut off automatically. The Duct Sizing Rules of Thumb provide some guidelines on proper duct sizing. If you are unsure of the proper duct and blower size to use consult your local heating contractor.

10. DUCT SIZING RULES OF THUMB

Size of Collector	Duct Length	Size of Ductwork
32 sq. ft.	20' - 3 elbows	6" round
64 sq. ft.	15' - 3 elbows	6" round
64 sq. ft.	20'+ - 3+ elbows	8" round
120 sq. ft.	15' - 3 elbows	8" round
120 sq. ft.	20'+ - 3+ elbows	10" round

In the situation where a long duct run is required and there is weak air velocity coming out of the outlets, a small in-line fan can be placed near the outlet inside the ducting to help speed air delivery.

Sizing Outlets

Cold air returns and hot air outlets must be correctly sized so as not to create a bottleneck in the system. A good rule of thumb for sizing the inlet/outlets is:

DISTANCE BETWEEN BAFFLES x AIR GAP x 1.5

For example, if the baffles are spaced 24" apart with a 1" air gap:

24" x 1" x 1.5 = 36 square inch outlet size.

For the above collector a 4x10 or 4x12 air register would be adequate. Inlets and outlets should be slightly larger for passive systems.

Pulling vs Pushing Air

Some solar designer advocate pulling the air through the collectors, others recommend pushing the air through. Either way will work, each has certain advantages and disadvantages.

PUSHING the air through the collector increases the static pressure within the collector. This must be taken into account when sizing the blower and ducting. Higher static pressure results in hotter collectors which increases the amount of heat loss.

PULLING the air is the most efficient method since there is less chance of air escaping the collector through minor cracks. In order to prevent the blower motor from overheating, only blowers whose motors are mounted out of the warm air stream should be used when pulling the air.

Backdraft Dampers

All the heat gained from solar collectors during the day will be lost at night if a back-draft damper is not installed in the ducting or on the blower. At night the cold air in the collector will sink to the bottom of the collector and through the ducting into the living area causing a chill in the room. Warm air in the house will simultaneously be drawn into the system through the hot air outlets and it too will be cooled. This is called reverse thermosiphoning. Backdraft dampers are relatively easy to build and will prevent thermosiphoning from occurring.

Collector Temperature

To check if the blower and ducting have been sized properly, measure the outlet temperatures. Temperatures from the collector should be between 90 and 120 degrees Farenheit. Higher temperatures result in more heat loss through the glazing. Lower temperatures won't heat the house.

To test temperature, place a small thermometer in the hot air outlets. If it is much higher than 120 degrees, the blower and/or ductwork could be too small. If air velocity feels somewhat weak, try increasing the size of the ductwork if possible, rather than moving to a larger blower (which will only increase static pressure). After that, if the air is still too hot, increase blower size.

If the air is much cooler than 90 degrees and if the blower keeps cycling (turning on and off constantly), the blower may be too large for the system.

Protecting Collectors From Stagnation Temperatures

Unless collectors are made from materials which can definitely withstand stagnation temperatures (approximately 400°F), steps must be taken to protect them from these extremely high temperatures.

Stagnation temperatures occur during power failure or when controls fail, during spring and fall when they are frequently not required for space heating, and during the summer. A big advantage of vertical wall collectors is that they do not receive the sun's direct rays in the summer because it is higher in the sky (see illustration). Vertical wall collectors, however, still receive some insolation in the summer which can produce stagnation temperatures.

Solutions to stagnation temperatures include overhangs, venting, and covering.

OVERHANGS

Oftentimes the building's roof overhang is adequate to shade the collectors in the summer. Or, a simple overhang can be built. This will not, however, protect collectors in other seasons when the sun shines directly into the collector (such as during power failure).

VENTING

Venting the heat outside prevents stagnation temperatures from damaging materials. Venting can be done:

Manually - by creating a vent which can be opened in the summer and closed in the winter (steps must be taken to prevent dust and moisture from entering the collector).

Automatic Temp-Vents - simple, inexpensive devices made from bi-metallic strips and silicone gasketing which can be adjusted to open and close anywhere between 140° and 180°F automatically (no power required). These should be installed at the top and bottom of the collector box for adequate air flow.

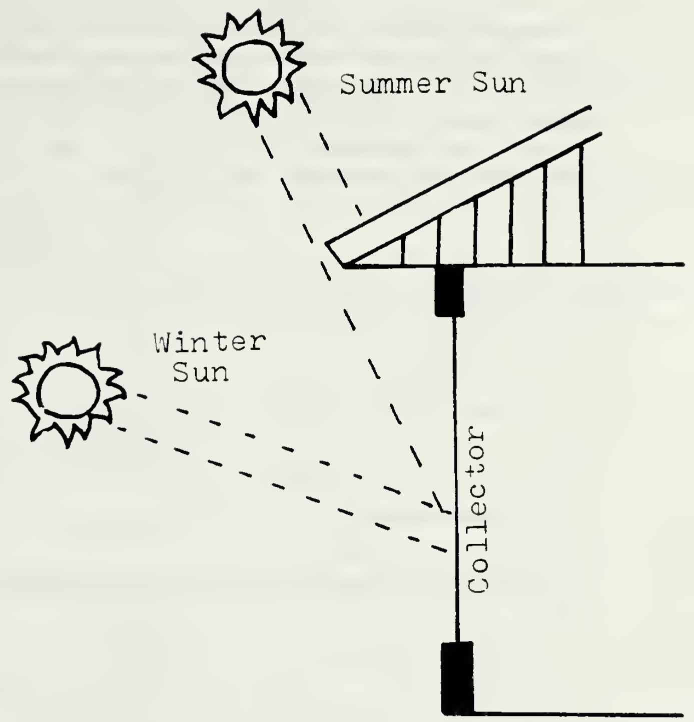
Power Venting - the system is designed so that the blower is activated to exhaust the air outside the collector rather than into the house.

REFLECTOR DOORS

Reflector doors serve two purposes—to protect the collector and to reflect solar radiation into the collector. During the summer, and on days when the collectors are not being used, the reflector doors can be closed to prevent the collector from overheating. This also protects the glazing from baseballs, rocks, and vandals. During the winter reflectors increase the amount of solar energy striking the collector by 10%-30%.

Reflector doors can be constructed of wood, metal, or any variety of materials. Don't make them so heavy that they are difficult to raise and lower (sometimes it is easier to build several smaller doors rather than one large one). Heavy-duty aluminum foil, rigid fiberglass insulation with a reflective facing (also helps insulate collector when door is closed), or any durable reflective material can be used for the reflector. Even painting the inside of the doors with bright white paint will help.

Heavy-duty hinges and bolts must be used to prevent wind damage. Painting the outside of the doors to match the house will not only improve the appearance, but will prolong the life of the doors as well.



11. Angle of Sun in Winter & Summer

MATERIALS

A solar collector system is a big investment. If you purchase a commercial system you will invest more money than in a home-built system, where you will be investing more time.

One advantage to providing the labor yourself is that it might allow you to purchase a higher grade of materials or build a larger system than if you bought a commercial system.

The primary rule of thumb to remember when choosing collector materials is

BUY THE HIGHEST QUALITY COLLECTOR MATERIALS YOU CAN AFFORD

The solar system's environment is very severe. A collector will be exposed to ultraviolet radiation which can damage plastics, rubbers, and paints. Moisture entering the collector can cause some insulations to degrade, can ruin the absorber coating, or fog the glazing. Montana solar collectors must withstand temperatures from -30°F to over 200°F—sometimes all in the same day! Temperature extremes like that cause some materials to expand and contract significantly. Overheating in summer will cause some plastics and sealants to soften, sag or warp. Collectors must be able to withstand high winds and hailstones. When designing and building a solar collector keep in mind the extreme environmental conditions that it must withstand if it is to have a long, productive life.

RULES OF THUMB

* Use proven materials. When in doubt as to a material's suitability ask an expert before buying it.
* Understand the characteristics of the materials before using them. Know their maximum operating temperatures, expansion characteristics, durability, etc.
* Design the collector before purchasing the materials.

Glazing

Tempered Glass is the best glazing material for solar collectors and is generally regarded as the most attractive. It is durable, withstands high temperatures, and is fairly easy to work with. Glass is heavy and can be relatively expensive. Patio door replacements, available at many hardware stores and glass supply outlets, make excellent collector glazing. Low-iron solar glass is ideal, but it is not widely available and is more expensive.

Under no circumstances should you use plate glass. It is a hazard when it breaks (people could fall into it), and it doesn't hold up well under high temperatures and large hailstones.

SOLAR GLAZINGS

Type Cost Sq. Ft.	Brand	Advantages	Disadvantages	Thickness	Solar Transmittance	Infrared Transmittance	Maximum Operating Temp	U-Value	Durability
$ 70 to $1 50	Single strength	Transparent Excellent selective transmission	Expensive Breaks easily	3/32	85%	2%	400°	1 13	Resistant to scratching
Glass $ 95 to $2 05	Double strength	Excellent appearance Small expansion and contraction	Heavy Installation difficult	1/8	85%	2%	400°	1 13	Lifespan indefinite if not broken
$2 to $6	Thermopane	Easy to clean		9/16	75%	1%	400°		Stays relatively clean
Polycarbonate Sheet $1 25 to $3 25	Tuffok* Lexan* Twinwall* Cyrolon*	Transparent Virtually unbreakable Higher operating temp than acrylics Easy to install Lightweight	Scratches easily Expensive Combustible High expansion and contraction Holds dirt Deflection with ΔT	125 250 220	85% 80% 77%	6% 0%		99 92 85	Slight color Change and embrittlement Transmittance lowered by UV over time
$1 00 to $2 00	Plexiglas*	Transparent or translucent	High expansion and contraction	125	92%	1%	170°	1 06	Excellent weatherability
Acrylics $2 50 to $3 50	Exolite SOP* (formally Acrylite SDP)	Easy to install Excellent appearance Lightweight Good optics	Expensive Panel will bend or deflect when its two surfaces are at different temp	630	83%	1%	170°		UV resistance 25 yr lifetime
Fiberglass Reinforced Polyester FRP	Filon*	Even diffusion of light Easy to handle	Transparent not available Wavy appearance	038	86%	4%	225°	95	Yellows with age
	Lascolite*	Good strength & durability	Moves with temperature changes	040	86%	4%	225°	95	
Flat & Corrugated $ 80 to $1 20 flat $ 50 to $ 75 corrugated	Kalwall Sunlite* (flat or corrugated)	(specify tedlar coated Premium or Filoplated for UV resistance) Low cost Corrugated is stronger and works well overhead Good availability	Corrugated requires special hardware Corrugated has lower solar transmittance and greater heat loss because of increased surface area	040	86%	4%	225°	95	Glass fibers blossom or protrude with age (can be refinished with resin) 5-15 yr lifespan Durability poor with UV inhibitor
	Sunlite Premium II Factory panel Sunwall*	Sunwall is very easy to install		2 3/4	73%	2%	225°	41	Fastener holes enlarge with movement
Polyester Film $ 38 to $ 64	3M Flexigard* acrylic-polyester	Low Cost Easy to install UV resistant	Scratches easily Infrared transmission	008	89%	9 5%	275°		Lifespan 10-15 years
	Chemplast Llumar*	Very strong for a film		005 007''	89% 89%		350° 350°		Clarity retained when scratched
Polyvinyl Cloride Film	DuPont Tedlar*	Extremely strong Lightweight frame can be used	Difficult to figure heat shrinkage (on installation) Infrared transmission	004	90%	45%	225°		Lifespan 4-10 years Becomes brittle with age lasting trans-mission
Fluorocarbon Film $ 86	DuPont Teflon*	High resistance to heat weather and chemicals High solar transmittance Good choice for inner glazing Outstanding transparent clarity	Infrared transmission Expensive Most adhesives will not stick	001''	96%	58%	400°		Lifespan 5-15 yrs Stretches with age Lasting trans-mission
Polyethylene $ 03 to $ 10	Many brands	Very low cost Light flexible easy to install Good inner glazing	Short lifespan High transparency to infrared radiation Wind and temperature sogging	004	78%	70%	140°		Use as inner glazing Lifespan 6 mo to 3 yrs

14. (Note: The prices shown above are 1980 prices)

1980 NCAT Grants Division JTX

Many home-owner built collectors use **fiberglass reinforced polyester** (**FRP**) since it is easy to handle and can be cut to the desired size. Ultraviolet rays cause it to cloud, which lowers transmittance. This will reduce collector efficiency.

It is also not as attractive nor as durable as tempered glass. Commonly used brands of solar-grade FRP's include Filon, Sunlite, and Lascolite. Common patio-grade fiberglass is not recommended since it begins clouding immediately.

Plastics, such as polycarbonates and acrylics are not locally available but are marketed for solar collectors. **Polycarbonates**, sold under tradenames of Tuffak, Lexan, Twinwall, Cyrolon, are virtually unbreakable but they are easily scratched from the combined effects of dust, wind, and hail. Since they scratch so easily, they are also difficult to clean. Polycarbonates can be quite expensive.

Acrylics have extremely low maximum operating temperatures and will expand and sag when exposed to high temperatures. Temperatures differentials (between the inner glazing and outer glazing) will cause them to warp. Although they are sometimes marketed for solar applications they cannot be recommended for collector glazings.

Thin films (brand names include Chemplast Llumar, 3M Flexigard, DuPont Tedlar and Teflon, and polyethylenes) offer economical glazing choices. They are strong, easy to install and provide good solar transmittance. Cost can vary from cheap to relatively expensive--quality varies as well. Deterioration from ultraviolet rays and their tendency to sag over a period of time (resulting in an unattractive glazing), as well as their limited lifespan, are their main drawbacks.[7]

GLAZING RULES OF THUMB

* Double-glaze collectors to minimize heat loss
* Buy the best quality glazing you can afford
* Know durability, expansion characteristics, maximum operating temperatures, and warranty information prior to purchase

Absorbers

Absorbers are usually made from metals that will absorb the sun's energy on its surface and transfer it to the air flowing by. Absorbers should be durable, easy to install and paint, and transfer heat readily to the air chamber located behind it. Commonly used materials include copper, aluminum, and steel.

Copper is the best absorber material. Its cost usually makes it impractical for most do-it-yourselfers to consider.

Galvanized metal and **aluminum** are the most commonly used absorbers. They are locally available, easy to cut and to install. Treat with mild acid solution (vinegar or muratic acid) prior to painting.

Primed steel siding or **aluminum trailer siding** are also good absorber choices. Simply cut to size, prep with mild acid solution and paint with absorber coating prior to installing.

Aluminum **litho-plate** (available from your local newspaper) is flat and easy to install. It does not have corrugations or a textured surface which is a drawback since corrugations increase air turbulence. Its major advantage is that it is cheap. Paint the printing side (after thoroughly cleaning and priming) and install the shiny side into the air stream.[8]

Selective surface absorbers are available in lots of varieties . . . chrome, nickel, iron oxide, porcelain, copper, etc. They absorb maximum amounts of solar radiation (shortwave) while emitting very little infrared (longwave) radiation which results in less heat loss through the glazing. They can improve collector efficiency significantly, but are usually expensive and often not locally available.

ABSORBER RULES OF THUMB

* Use the thinnest gauge available—it is more efficient
* Clean and prep absorber surfaces properly (prime if necessary)
* Using corrugated or textured surfaces (to tumble the air) will maximize heat transfer from the absorber to the air
* It is not necessary to paint the back of the absorber

Absorber Coatings

Absorbers are painted to increase heat absorption. Solar collector paints must be able to withstand high temperatures, should apply easily and adhere well, and should dry to a flat black finish. Be absolutely sure that the paint can withstand high temperatures since it will outgas noxious fumes and/or eventually flake off the absorber if it can't. A completely flat finish is best—any degree of glossiness will reflect light away.

Commonly used paints include W.W. Grainger's Demcote, Rustoleum Flat Black or Midnight Black, Columbia's Solar Black, and high-temperature barbecue and stove paints. Selective paints (with high absorption and low emittance) are also available in some areas.

COATING RULES OF THUMB

* Treat galvanized metal and aluminum with mild acid before painting
* Apply paint as thinly as possible
* If surface is to be primed, be sure primer is compatible with the paint
* Read and follow directions on paint carefully

Insulation

Collectors must be insulated properly to prevent heat loss from occurring. Backs and sides should be insulated to at least R-4. Insulation also protects wood interiors from high temperatures which could eventually lead to the "charring" of the wood and the possibility of it catching on fire.

Use only insulations which can withstand high temperatures without degrading, shrinking, outgas, or releasing fibers into the air which would circulate into the house.

Appropriate insulations for collectors include **mineral fiber**, **foamed glass**, and some **thermoplastics**. Commonly available brands include Duct-Board, FoamGlas, and Thermax. Building-construction grade fiberglass is not suitable since it is formulated with large amounts of binders which break down at high collector temperatures.

High-temperature fiberglass board with a foil facing is the most commonly used insulation for do-it-yourselfers. It is rigid, making it easy to cut and install, and is made with little or no binders. It should be installed with the shiny side towards the air stream.

INSULATION RULES OF THUMB

* Use insulation rated for high temperatures
* Insulation should not degrade under repeated thermal cyclings (temperature extremes)
* Insulation should not slump, compact or settle

Framing

The collector framing provides a weathertight enclosure to keep moisture, dust, and cold air from entering the collector. It also provides a stable support for the glazing and for mounting the collector on the wall. Wood and metal frames are most commonly used by do-it-yourselfers. When considering what to use, take into account (1) availability, (2) ease of construction, (3) appearance, (4) weight, and (5) price.

Sealant

High-quality caulking is absolutely essential if the collector is to perform well. A solar collector sealant must resist ultraviolet radiation and effects of weather, must have excellent adhesion, and be able to withstand temperature cyclings—all without becoming brittle.

WHEN IN DOUBT---CAULK!

Silicone has been found to be the best caulk for solar collectors. Use it along seams wherever you join two sheets of material, seal the collector perimeter completely, and seal the layers in the collector. Silicone skins (begins to harden) quickly. Be sure the parts fit before caulking and work rapidly.

Ductwork

Ductwork which will have hot air running through it and any duct exposed to the elements must be insulated. Round or square sheet metal duct can be insulated with duct insulation and duct tape. Flexible round insulated duct, available from heating contractors and solar installers, will reduce installation time and expense. Be sure that your insulated duct is lined on the inside, otherwise fiberglass fibers will enter the house. Stretch it out completely before installing to smooth out the inside. Reducers and boots, also available from sheet-metal, heating, and solar contractors, will simplify installation of ducting.

Blowers

The blowers most widely used for solar collectors are shaded pole squirrel cage blowers. To prevent the motor from overheating, remember, only blowers with externally-mounted motors should be used.

Try to make the adapter, reducer, and boot hookups before crawling into the attic or crawl space to install the blower. Avoid attaching the blower to the floor or attic joists in order to reduce vibration and noise.

Thermostats

The line-voltage thermostat and electric heat thermostat, together with the blower, provide a system which works completely automatically. The line-voltage thermostat senses the collector temperature, while the electric heat thermostat senses the room temperature. When room temperature falls below the desired level, and if the collector has reached high enough temperatures, the blower will be activated. The blower will run until the house is warmed to the desired level and the electric heat thermostat shuts it off (or until the collectors become too cool).

The **remote bulb thermostat** is the line-voltage thermostat most commonly used. It has a sensing bulb which is inserted in the air gap behind the absorber near the top of the collector. The bulb is connected to the thermostat by a thin copper tube (be sure not to bend or crimp it.) The thermostat box should be located so that it is accessible for fine tuning.

The **electric heat thermostat** (the kind commonly used for forced air furnaces) is located next to the existing furnace thermostat, provided that it is in a spot which is neither too warm nor too cold.

FOR MORE INFORMATION
(on materials)

MODEL TEA SOLAR HEATING SYSTEM - Construction Manual, by Peter Temple and Jennifer A. Adams, 1980, Total Environmental Action, Harrisville, New Hampshire

SOLAR HEATING MATERIALS HANDBOOK — Environmental and Safety Considerations for Selection, U.S. Department of Energy, Washington, D.C.

GLAZING CHOICES (article), Solar Age Magazine (April 1979), Solar Age, Church Hill, Harrisville, NH 03450

CONTROLS DEMYSTIFIED (article), Solar Age Magazine (July 1980)

SOLAR ENERGY INDUSTRIES ASSOCIATION, 1001 Connecticut Ave. N.W., Suite 632, Washington, D.C. 20036

Heating Contractors or Solar Contractors can provide answers to many questions

CONSTRUCTION & INSTALLATION

The following set of instructions are for a 36 square foot solar air collector which, if properly constructed, will heat approximately 360 square feet of living area during sunny, daytime hours.

DESIGN THE SYSTEM BEFORE STARTING CONSTRUCTION

1. Decide where the panel will be mounted on the wall. Check walls for electrical outlets or obstructions. Note floor level inside home and its relation to the outside wall. Locate wall framing to place duct openings between studs.
2. Mark openings for ducts on outside walls.
3. Decide where you will locate hot air outlets and cold air returns in the house.
4. Decide where the ducting will run for heat delivery and cold air returns. Suggested duct locations: rim joists (the band of 2x10s which run around the perimeter of the floor joists), closets, attics, crawl spaces, and corners (corner of a room can be framed in and finished off to hide ductwork).
5. Decide where to locate thermostat and blower. Thermostats should be located in neither a very warm or cold spot. Next to the existing furnace thermostat is usually a good choice. Blowers should not be mounted on structural members, if at all possible, to reduce vibration and noise.
6. Decide where backdraft dampers will be located in the system. Cold air returns or on the blower are places where they are most commonly mounted.

SHOPPING LIST

Quantity	**Material**	**Estimated Price**
2 34x76"	Tempered thermopanes (patio doors)	175.00
55 sq. ft.	1" Duct-Board insulation	45.00
2 3x8	Corrugated enameled steel siding	50.00
8 tubes	High-temp silicone caulk	50.00
6 2x6	8' lengths for perimeter framing	15.00
3 3x8	30-gauge tin (for glazing supports, moulding, and baffles (SEE BAFFLING Option)	35.00
2 spray cans	High-temp flat black paint	10.00
1 265 CFM	Shaded-pole blower with external motor	48.00
1	Remote bulb line-voltage thermostat	50.00
1	Electric heat thermostat	22.00
1	Backdraft damper	5.00
20 ft.	6" Flex-Duct (estimated)	45.00

	MISCELLANEOUS	30.00
2 8" long	Tin pipe in 6" diameter	
2 6" long	Tin pipe in 6" diameter	
	Nails, screws, registers, blower, and duct adapters, exterior paint, duct tape, etc.	
	COST OF SYSTEM BEFORE TAX CREDITS	$580.00
	Less Federal Tax Credit	232.00
	Less Montana Tax Credit	29.00
	COST OF SYSTEM AFTER TAX CREDITS	$319.00

Step-by-Step Instructions

1. **FRAMING THE COLLECTOR** - initial framing using 2x6's. Cut two 74" long (top and bottom), two 79" long (center glass supports) and two 82" long (sides). For the initial framing, lay out the two 74" boards and the two 82" boards making a rectangle. Hold the ends of the 82" boards inside of and flush with the ends of the 74"ers. Use Max Bond (or a similar wood glue) in all joints and nail together. Glue and nail center glass supports in exact center of frame running vertically. These measurements provide a ½" gap for expansion of the glazing.
2. **CUT SLOT FOR AIR PASSAGE** - Standing frame on edge, mark a slot on the two center boards starting 5" from one end and up 1" from the edge. Mark a slot 3" wide x 20" long. Cut slot using a skill saw and a hand saw. This slot will be the air passage between the two boxes. Lay collector down on flat surface.
3. **INSULATE COLLECTOR** - Cut duct-board to just fit in the two rectangles and insert. Cut long rectangular pieces to line the sides, thus protecting all of the interior wood from the heat. Now that you have the insulation making a tray, a heat tape (can be purchased with the duct-board) should be ironed on all seams overlapping both pieces that you're bonding equally. Silicone can be used between the insulation and the wood to help hold the duct-board to the sides.

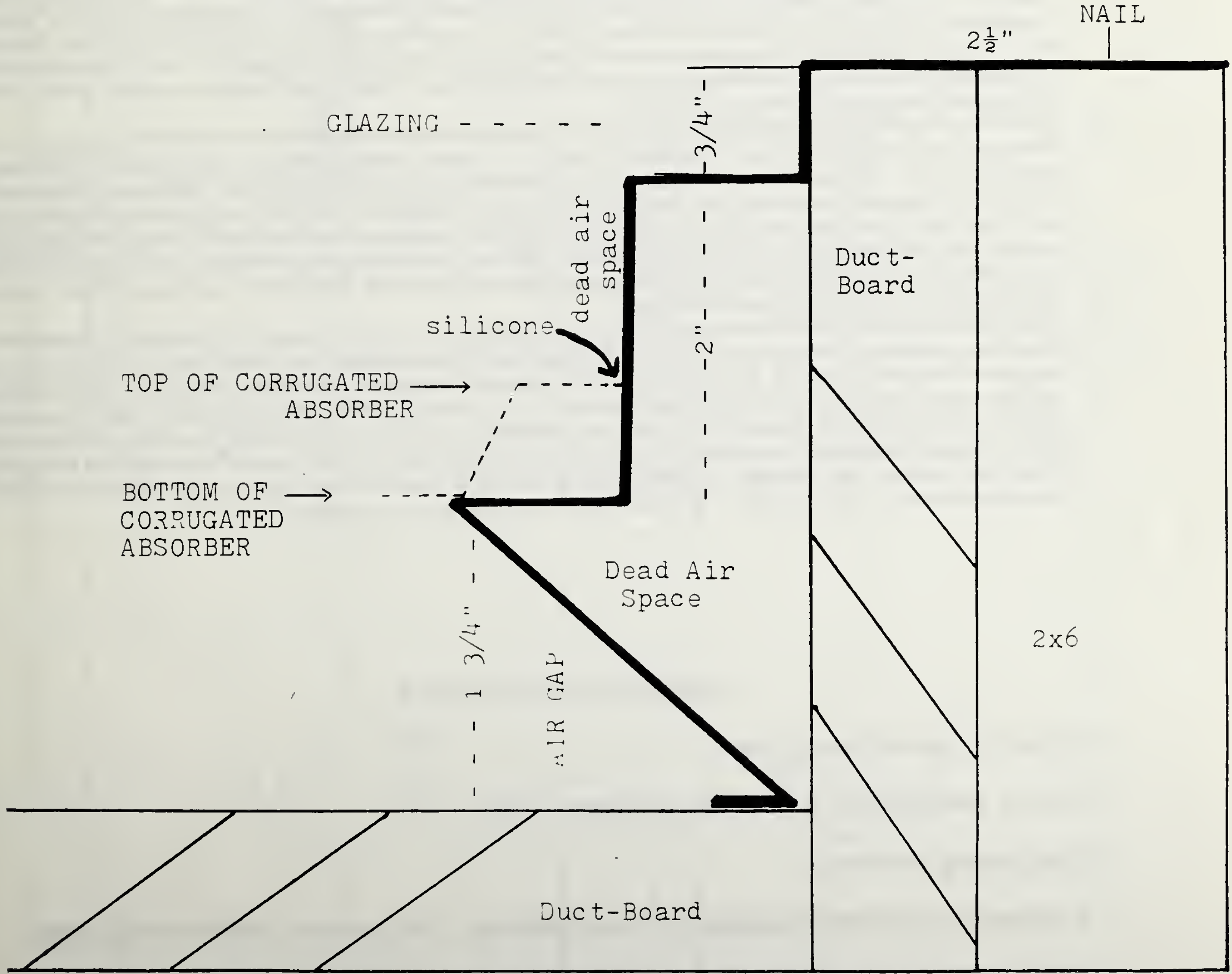
   Cut the duct-board out of the center air passage. To cover the exposed wood in the slot heat tape can be used . . . overlap the duct-board and iron on. Or, bond heavy-duty aluminum foil to the wood and the duct-board with silicone. Allow ample time to dry. A backing can be attached to the back of the collector at this point (such as plywood, cheap paneling) to help hold the duct-board in.
4. **ABSORBER AND GLASS SUPPORTS**

   Option #1 - Tin: Tin is handy, for all of the supports can be built in one piece. Skill in working with tin (and the tools) or a tin shop is required. Cut the following strips (all one foot wide): Four 77" (for sides and center supports), four 35" for top and bottom supports. Start with 1½" lip on top of the 2x6, jutting down just inside of the duct-board ¾" down to accomodate the glass, extending then perpendicular to the duct-board for 1" (this forms the glass support). Then drop down 2" before bending perpendicular again for 1" to provide a support for the absorber. From there, bend the tin at a 45° angle into the corner where the duct-board on the back meets the duct-board on the sides. See illustration #13. To prevent the tin from tearing the seam of the duct-board, a slight lip should be bent on the edge of the tin. This type of support has the advantage of providing a dead air space around the sides of the collector. Prior to mounting the perimeter supports, the two center supports must be slotted for the center air passage. Also, the side or end pieces should be cut at a 45° angle to provide tight corners, sealing the seams with silicone. Supports are fastened to the collector frame by nailing into the 2x6 every 10-12 inches.

   Option #2 - Wood: If preferred, 1x2 wood strips can be used for glass and absorber supports. If this method is used the 1x2's must be nailed to the perimeter frame prior to insulating the sides. After they are fastened, provide for the same air spaces ¾" down from the top of the 2x6 for the glass support and the absorber support nailed below to provide a 2" air space between absorber and glass. After these are nailed on, the sides must be lined with heavy-duty foil rather than insulation. The foil should be stapled and a light application of silicone applied to seams.
5. **BAFFLING THE COLLECTOR** - In this design the baffles are attached to the same end as the outlets. Again, the best material to use is tin. A simple tin channel, 1¾" high, can be bent for the absorber to rest upon. Two baffles, approximately 59" long are required which results in baffles 17" shorter than the height of the box. There is also a 17" space between the baffles. This provides an even flow of air throughout the collector (see illustration #16). The baffles can be notched to fit snugly against the glass and absorber supports and attached with screws to those supports. Silicone under all the baffles, let dry, holding it in place until the absorber is screwed to the baffles. Again, if preferred, wood baffles may be used instead of tin. They must be completely wrapped with heavy-duty aluminum foil to protect the wood.
6. **COLLECTOR OUTLETS** - Using the 8" lengths of 6"-diameter tin pipe as a guide, cut a 6" hole in each corner of the same end as the center air passage. Elevate the collector box on blocks high enough to install the pipes to protrude from the back. Make 1" long cuts on one end of the pipe every 1" to 1½" and bend them perpendicular to the pipe and away from the pipe's center. Slide the pipe through the duct-board from the inside of the collector until the tabs make contact. Silicone the pipe on the front and back of the duct-board and allow to dry. Allow the silicone to cure on the baffles and pipes.
7. **INSTALL REMOTE BULB THERMOSTAT** - Clamp the sensor bulb to the top of the collector under the absorber and run the line out one of the outlets making sure not to crimp the tube. The tube should then be siliconed to the duct-board to prevent crimping later. Mount the control box in a convenient spot (on the wall or side of collector). Set sensor to actuate blower when temperature in collector reaches 90°F. Set differential to turn blower off when air cools to 78° - 80°F.

8. **ABSORBER INSTALLATION** - Clean absorber material with vinegar, muratic acid or Easy Surface Prep (available where paint is sold) to remove any film from absorber. Use dark brown or black steel siding if possible (if paint should chip off it will be less noticeable). Cut sheets wide enough to fit between framing with no more than 1/8" or 1/4" air gap for a tight fit. Lay corrugated sections in the collector so that air flows across corrugations (air should flow with corrugations on passive collectors). As the sheets are laid in, fasten to baffles and perimeter framing with sheet metal screws. Paint entire side facing the sun. Allow paint to cure and fill any gaps between frame and absorber with silicone to prevent air leaking into the dead air space between absorber and glazing. If possible, set collector in sun to let paint and silicone cure so that any out-gassing which might occur will not affect glazing at a later date.

Heavy black line indicates the tin piece described in, Step 8.



13. CROSS-SECTION OF ABSORBER & GLAZING SUPPORT Option #1 - Tin (This cross-section is to scale)

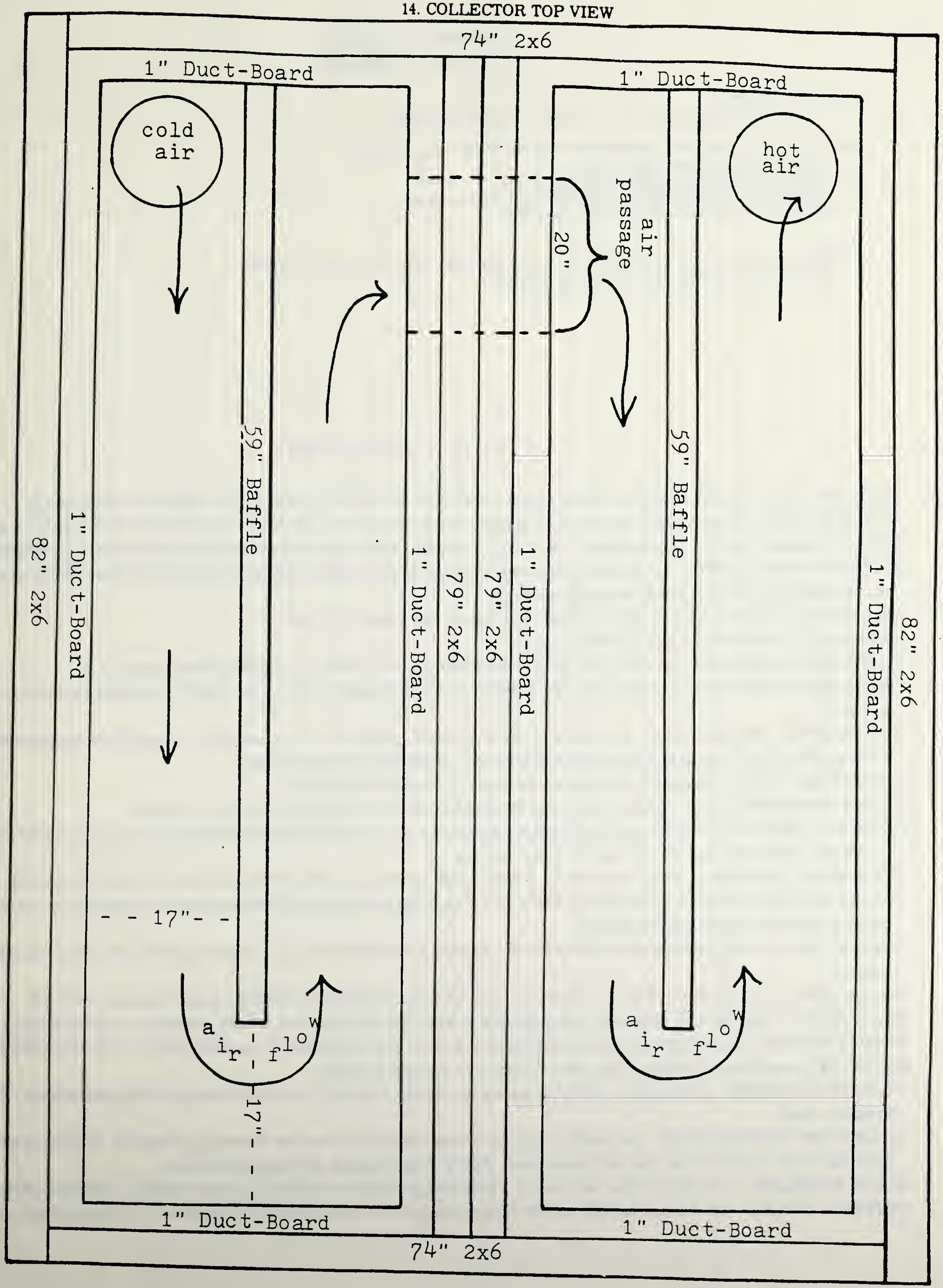
Before the glazing is set in, a pad should be laid down on the glass support to act as a cushion for the glass. Again, silicone should be used, making a pad at least 5/8" wide. Do not lay glazing onto uncured silicone (if glazing should ever need to be removed silicone makes such a bond as to make it practically impossible to remove the glass without breaking).

9. **MOUNTING COLLECTOR ON WALL** - To prepare for mounting on the wall, a section the size of the collector should be marked out and holes cut for the outlets. Try to keep holes slightly larger than the pipes for ease of installation. If the wall is wood lap siding, a skill saw using a shallow cut can be used to strip the siding, exposing the sheathing underneath. This provides a totally flat surface for the collector. It isn't absolutely necessary to remove the siding. The collector can be toe-nailed to the siding with gaps being filled with silicone. After the collector is toe-nailed to the wall (every foot) angle brackets should be added underneath to provide extra support. If there is no room underneath try to fit a bracket on the sides so the weight is supported by more than just nails.
10. **INSTALLATION OF GLAZING** - After the collector is firmly mounted, the glazing can be set in. First, clean the glass thoroughly. Set glass in. With glass in collector a perimeter moulding is added to hold the thermopanes in. Wood can be used. However, a tin angle moulding which overlaps the glass and wraps around the corner of the collector making contact with the building is preferred. The section of tin against the glass should be folded under creating a smooth surface against the glass as well as making a definite corner for easier application of silicone. The edge that runs against the south wall can have a 90° angle bent with a large enough edge to apply screws through the tin into the wall. Screw through the tin into the front edge of the 2x6 frame of the collector. This tin moulding not only adds strength but also covers the wood making the system weatherproof. If painting the trim is desired, a paintable galvanized tin called paint-loc should be used. Silicone where moulding meets glass.
11. **DAMPER** - One type of damper that can be mounted in the cold air return consists of a piece of plastic, vinyl, or light aluminum that just fits in the duct and is attached at the top to a piece of ½" hardware cloth which fills the hole of the duct. When the blower pulls air, the damper opens (the damper is mounted in the cold air return outlet in the house). When the blower stops the damper falls against the hardware cloth preventing reverse thermosiphoning. If this type isn't feasible, consult a heating contractor on how to install the damper directly to the blower.
12. **DUCTING & BLOWER INSTALLATION** - If the duct run is greater than 20 feet, the blower should be located nearer to the outlet rather than the collector because of resistance in the line. To fasten insulated flexible round ductwork to a blower, use a 6" length of tin pipe. Cut tabs 1" long every 1" apart around one end of the pipe. Fold tabs out at right angles to the pipe. This piece is screwed to the blower on the inlet side. The outlet of the blower is square. On the other tin pipe cut four 3" cuts equally spaced so the pipe can be fashioned into a square and screwed on. After the pipes are attached, tape the seams with good quality duct tape to make them airtight. Attach ducting to outlets in collector with screws and/or duct tape, sealing well with the duct tape. One method of hanging the blower is by screwing an angle iron to each side of the blower making sure the oil hole is up. The angles can then be bolted to a vertical surface.
13. **COLD AND HOT AIR REGISTERS** - An easy way of placing registers for cold air returns is by using an inside wall since they are generally uninsulated. Be sure there are no obstructions inside the wall which would block air flow. Cut a slot to accept the register at floor level in the wall. In the attic cut a slot to attach a tin boot above the register in the room. With the register on and the boot on top, fasten your cold air duct from the collector to the boot in the attic. The hot air outlet should be mounted near the floor level if at all possible. However, if you have no alternative other than to come through the ceiling joists, fasten the hot air duct and mount the register on the ceiling. The cold air return on the floor level will pull the hot air from the ceiling to the floor. After duct runs have been installed, the electric heat thermostat is mounted in the living area and wired to the blower and line voltage thermostat (in the collector). This should be done by a licensed electrician.

PERIODIC MAINTENANCE

* Oil blower once or twice a year
* Cover or vent collector in summer (see design section)
* Clean glazing as needed
* If desired, scrape frost off glazing on winter mornings. This results in earlier start-up times
* Pay attention to your system. If it isn't working as well as it once was, check for air leaks or fan/thermostat problems.

14. COLLECTOR TOP VIEW



FOR MORE INFORMATION
(on collector construction)

Books Previously Listed:
Model-TEA Solar Heating System, Solar Air Collectors, Simple Solar Air Heaters

Books Available from Solar Components Corporation, P.O. Box 237, Manchester, NH 03105:
SOLAR RETROFIT by Daniel K. Reif @ $11.95
SOLAR AIR HEATER by Roy Wolf, Rodale Press @ $14.95
BUILD-IT BOOK OF SOLAR HEATING PROJECTS by William Foster @ $5.95
HOW TO BUILD A SOLAR HEATER by Ted Lucas @ $2.50

Articles:
SOLAR INSTALLATION SUCCESSES - Sept. 1977 Solar Age Magazine, Church Hill, Harrisville, NH 03450
SITE BUILT COLLECTORS - April 1979 Solar Age Magazine

Terms & Definitions

ABSORBER - the blackened surface in a solar collector that absorbs the solar radiation and converts it to heat energy

ACTIVE SYSTEM - a solar heating system which uses blowers to transport the air from the collectors into the house for space heat

BTU - the standard unit of measurement of heat (1 BTU is needed to raise the temperature of 1 pound of water 1° Farenheit)

BACKUP HEATING SYSTEM - the heating system used when there isn't adequate sunlight (cloudy or extremely cold days, night) to heat the residence, i.e. furnace, woodstove, heat pump, etc.

COLLECTOR - the device used to collect radiant solar energy and convert it to heat

CONDUCTION - heat transfer through a solid mass

CONTROLS - devices used to run solar heat systems automatically i.e. blowers, thermostats, heat sensors, etc.

CONVECTION - heat transfer through a fluid (air or water) by currents caused by the natural fall of heavy cool air and the rise of lighter, warm air

DIFFERENTIAL THERMOSTAT - an automatic electric control system using two sensors to measure the temperature difference between two points (such as temperature in the collector and temperature in the house)

DIFFUSE RADIATION - sunlight that is scattered such as on cloudy or hazy days

DIRECT RADIATION - solar radiation that comes straight from the sun casting shadows on a clear day

DOUBLE-GLAZING - when two sheets of transparent material are used to cover the absorber plate in solar collectors (this creates a dead air space) which helps prevent heat loss from the collector

EFFICIENCY - the ability of a solar collector to convert a high percentage of the BTU's striking the collector into usable heat

FLAT-PLATE COLLECTOR - a solar collector which uses a large, flat absorber sheet that faces the sun and which does not use mirrors or lenses to focus the sunlight on the collector

GLAZING - glass or other transparent material which transmits sunlight and acts as a barrier to prevent heat from radiating out of the collector

INSOLATION - the total amount of solar radiation (direct, diffuse, and reflected) striking a surface exposed to the sky

INSULATION - a material with relatively high resistance to heat flow (R-value) that is used principally to retard the flow of heat

PASSIVE SYSTEM - a solar heating system which requires little, if any, mechanical or external power to move the collected solar heat

RETROFIT - the process of adding a solar heat system to an existing building

SELECTIVE SURFACE - an absorber material or coating formulated to absorb the available sunlight while emitting very little thermal radiation (heat)

STAGNATION TEMPERATURE - potentially destructive temperatures that can be reached in collectors when collectors are not in operation (such as when house does not require heat, during power failures, or failure of controls)

STATIC PRESSURE - a measure of the resistance to movement of forced air through a system caused by ductwork, inlets, etc.

THERMAL CYCLING - the continuous high and low temperatures which a solar collector is subjected to during normal operation

20 copies of this public document were published at an estimated cost of $2.25 per copy, for a total cost of $45.00, which includes $45.00 for printing and $.00 for distribution.